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DIRECTED DISCOVERY VS. PROGRAMED INSTRUCTION--A TEST OF A THEORETICAL POSITION INVOLVING EDUCATIONAL TECHNOLOGY.

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THIS STUDY SOUGHT TO DETERMINE IF HIGHLY DIRECTED (PROGRAMED) LEARNING IS SUPERIOR TO NONDIRECTED (DISCOVERY-TYPE) LEARNING. SPECIAL UNITS IN MATHEMATICS WHICH EMPLOYED A DISCOVERY METHOD WERE DEVELOPED AT THE FIFTH-GRADE LEVEL. NEXT, A PROGRAMED MODIFICATION OF THE BASIC UNIT OF INSTRUCTION WAS DEVELOPED. FINALLY, ANOTHER PROGRAM OF INSTRUCTION WAS DEVELOPED TO TEACH THE SAME INSTRUCTIONAL OBJECTIVES AS THE BASIC INSTRUCTIONAL UNIT, BUT WITHOUT EMPLOYING THE DISCOVERY METHOD. THE PROGRAMED MATERIALS WERE DEVELOPED SO THAT A HIGHLY DETAILED DOCUMENTATION OF THE PROGRAM DESIGN COULD BE PROVIDED. THE EVIDENCE OBTAINED INDICATED THAT THE DESIRABLE LEARNING OUTCOMES WHICH SOMETIMES RESULT FROM LEARNING-BY-DISCOVERY CANNOT BE ADEQUATELY EXPLAINED IN TERMS OF OPERANT CONDITIONING. IT IS POSSIBLE, MOREOVER, THAT SEARCHING BEHAVIOR MAY NOT BE LEARNED FROM A DISCOVERY-TYPE INSTRUCTIONAL EXPERIENCE AT ALL. AS A RESULT, THE PROJECT IMPLICATIONS DEAL MORE WITH DESIGNING INSTRUCTIONAL UNITS THAN WITH THE RESEARCH PROBLEM, LEARNING-BY-DISCOVERY. (GD)

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Bert Y. Kersh

Final Report

Title VII Project Number 907

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teaching research

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Preface

After this report was written, the Sixty-third Yearbook of the National Society of the Study of Education was distributed. Part I of the yearbook, Theories of Learning and Instruction, includes chapters written by researchers whose interests evidently are very close to mine. The reader's attention is directed particularly to chapters written by J. W. Getzels, N. L. Gage, and Jerome S. Bruner in Part I of the NSSE yearbook for a somewhat different approach to some of the same problems discussed in this present report.

B.Y.K.

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I. The Experiment

Increasingly more importance is being placed on the teaching method frequently labeled "the discovery method." Representative of this increasing emphasis are substantial curriculum efforts in mathematics and science (Beberman, 1958; Davis, 1960; Suchman, 1961; and Finlay, 1960, to name a few) and programatic research endeavors on cognition such as those ongoing at the Harvard Center for Cognitive Studies. Numerous independent research efforts under such headings as "self-directed study," and "independent discovery," attest further to the professional concern being given to the so-called discovery method.

Learning by programed self-instruction is also still very much in the forefront of educators' attention today, even though the "teaching machine" fad may have passed. To date the major contribution of the teaching machine movement in education has been a methodology for developing instructional materials. This methodology is characterized by a process of repeatedly trying out and revising instructional materials to a point where they have some predictive utility. Analogous techniques for revising all kinds of instructional materials on the basis of student feedback are under development, and there is every reason to think that practicable procedures for "programing" even such costly media as motion pictures and textbooks will be available in the future.

Programed self-instruction and the "discovery method" are very different instructional procedures. Typically, by the discovery method, learning takes place with little or no direction from the teacher so that when the learning objective is attained it may be said that the learner "discovered" it. By contrast, programed instruction characteristically guides the learner one small step at a time toward the

instructional objective in such a manner that the learner typically does not have to search far in his efforts to ascertain what is being taught. The amount of guidance or direction provided during instruction is the most obviously different teaching variable when comparisons are made between the discovery method and programed instruction.

Problem

The attention being given both discovery and programed instructional methods serves to revive an older, unresolved research problem in a new context, and with greater potential for solution. The problem is to determine which process of learning is superior, (1) highly directed (programed) learning in which the learner is almost completely dependent on the teacher, or (2) non-directed (discovery-type) learning in which the learner must rely more heavily on his own cognitive capabilities. Advocates of the non-directed (hereafter called "discovery") instructional procedure claim a number of advantages, most of which are included in a recent article by Bruner (1961). Bruner suggests that learning by discovery benefits the learner in four ways: (1) his ability to learn related material is increased, (2) his interest in the activity itself is developed, rather than in the rewards which may follow from the learning, (3) his ability to approach problems in a way that will more likely lead to a solution is developed, and (4) he tends to more easily retrieve or reconstruct from memory material which he has learned.

Related Research

Implicit in such claims is the assumption that opportunities for learners to engage in exploratory or "searching" behavior decrease when

greater amounts of guidance are provided during instruction. Congruently, as opportunities for exploration and manipulation decrease, so does the potential for attaining the benefits ascribed by Bruner. Actually, the related research evidence pertinent to this point is equivocal. One reviewer suggested that, if anything, the research evidence does not support claims such as Bruner makes (Ausubel, 1961). Other reviewers suggested that the somewhat inconsistent findings by researchers in recent years may actually reflect different learning outcomes resulting from two or three quite different "discovery learning" processes (Kersh & Wittrock, 1962).

Two studies illustrate contrasting conditions under which learning may occur in the name of the discovery method. In one study (Kersh, 1958) college-level subjects (Ss) were asked to learn two rules of addition, each of which was relatively novel so far as the learners were concerned. The Ss were divided into three groups, each group receiving differing amounts of guidance as they learned the addition rules. The "discovery group" was given examples of the rules of addition and instructed to find a quicker or different way of summing the series. A second group was given the same examples but with more guidance in the form of clues in the way the materials were presented and in comments from the Experimenter (E). The third group was told the rules and instructed to practice them on the examples provided. When working with Ss in the discovery group, E asked the learner to "think aloud" or to write down his responses at every step of the way. E was present at all times giving encouragement continually. His main purpose was to keep the learner going in hopes that he would eventually arrive at the correct solution. The Ss, under these conditions characteristically

engaged in a process of thinking which has been described as "abduction" or "retroduction" (Hanson, 1958, p. 85). Retroduction is similar to induction but has the added feature of hypothesis formation. When reasoning retroductively, S does not simply test an old theory on new examples. First he formulates a hypothesis by searching for patterns in the data provided, and then he tests.

By contrast, Kittell (1957) reported an experiment which employed a word task with sixth-grade subjects. Learners in the discovery group (Kittell's Minimum Direction Group) were first given examples of the principles involved and then instructed to discover as many other principles as they could from other word sets. They were instructed to underline the word that did not belong with the others of a particular set and were informed immediately upon selecting a word whether or not it was correct. If right, they proceeded to the next problem set; if wrong, they tried again. They were instructed to guess if they did not know the answer. On the average, they discovered less than three principles out of fifteen. Since they were reinforced only when they underlined the correct word, and so few principles were learned, Ss must have had relatively few success experiences.

A second group in Kittell's experiment, the intermediate group, was told the general rule to each set of words but not the correct word. The third group, which learned under conditions in which they were given maximum direction, was told not only the principle but also the answer to each of the examples.

In Kittell's study, the group given intermediate direction was superior to the other two groups in their ability to apply the principles learned and to discover new principles from new examples. In

the Kersh study the group given maximum direction was superior on a test immediately after instruction; however, after one month, the effect reversed and the discovery group was found to be superior. The delayed, superior performance of the discovery group in the Kersh experiment was attributed to post-experimental practice. It was hypothesized that individuals in the discovery group were motivated to continue their efforts to learn the rules and to practice them after the formal learning period had ceased.

The findings of the two experiments may actually reflect different learning outcomes resulting from two quite different processes of learning by discovery. It would have been surprising if the learners in the Kittell study had been motivated to practice after instruction, in view of their relatively limited opportunity to explore and to manipulate word relationships and in view of their relatively low frequency of success experiences. In the Kersh study, learners had ample opportunity to engage in exploratory activity and were repeatedly reinforced for their efforts by E. Many Ss provided the solution rather suddenly after ten or fifteen minutes of repeated efforts to find the rule by manipulating the arrangement of numbers in the series in different ways.

Theoretical Position. One explanation for the superior performance of learners in discovery groups (as reported in such studies as Kersh, 1958, 1962; and Gagné, 1961) may be given in terms of operant conditioning. The learner, when required to discover solutions to problems without help, sometimes engages in a kind of exploratory behavior described hereafter as "searching behavior." When by familiar processes of operant conditioning, the searching behavior is reinforced during instruction, it will be learned along with the solution to the problem

(i.e., the subject-matter content). Searching behavior can be reinforced by E directly as in the Kersh experiment described above, or indirectly through programed feedback as in the Gagné and Brown experiment (1961). Having learned searching behavior, it is likely that the learner will continue to manifest such behavior "out of school" whenever it is appropriate. He may even create circumstances wherein he can repeat the same behaviors reinforced during instruction by asking his associates to "discover" what he did. In effect, he will continue to practice what he learned even after instruction, and such practice will continue to be reinforced occasionally. Theoretically, such a pattern of practice and reinforcement should enable the learner to "remember" and to use what he learned almost indefinitely, and very likely he will appear to others to be "motivated" or "interested in" what he learned.

If searching behavior can be suitably recognized and reinforced, it should not be necessary to rely completely on less efficient, time-consuming discovery techniques typically used today. Instead it should be possible to employ techniques of programed instruction to achieve the same desirable benefits which may accrue from learning by discovery.

The purpose of the present project was to conduct an experiment to test the hypotheses listed below and to determine whether the desirable learning outcomes associated with the discovery method (outlined above) may be attained through a system of programed instruction employing principles of operant conditioning as well as they can by typical classroom "discovery methods."

Hypotheses

1. Learners achieve an instructional objective at a faster rate when taught by programed (i.e., prescribed and empirically refined) in-

structional procedures than they do when taught by equally refined techniques which are not programed (i.e., which allow the instructor to use his own judgment in guiding the learning process).

2. Learners taught by a procedure which stimulates and reinforces "searching behavior" (i.e., behavioral manifestations of inductive and retroductive reasoning, problem solving, hypothesis testing and related complex cognitive processes) will more frequently than learners taught by a procedure which does not, (a) spontaneously employ the learned information and searching behaviors "out of school," and (b) recall and use the learned information and searching behaviors under appropriate (test) conditions.

Procedures

To conduct the experiment it was necessary to develop special units of instruction. First a special unit in mathematics was developed at the fifth-grade level which employed a discovery method. The unit was modeled after the materials and procedures employed by the University of Illinois Committee on School Mathematics (UICSM). The instructional procedures employed in the basic unit of instruction which was developed will be referred to hereafter as the "free discovery" procedure. Characteristically, the free discovery technique encouraged S to ascertain principles of mathematics from concrete examples of the principles. Each S would "discover" a principle independently and then show E that he had learned it. E did not permit a principle to be verbalized until after all Ss demonstrated by example that they had learned it. Typically, when Ss were working with a set of problems attempting to discover the principle involved, E worked with the learners individually, moving from S to S and communicating in whispers. Later the principle would be

discussed openly by the entire class. However, when a mathematical convention was to be learned (e.g., the order of operations) E explained it to the entire class after Ss had found from experience that a rule was needed.

The primary instructional objective was knowledge of the Distributive Law of arithmetic. Ss were also instructed in the UICSM terminology and notation so that they could employ abstract symbols in conceptualizing the distributive pattern. The first free discovery unit of instruction was tried out on several small groups of fifth graders and served as the basis for the programed materials developed subsequently. The free discovery procedure finally employed in the experiment actually was comparable to the programed discovery unit except that E was permitted to interact with the learners freely and to use his own judgment in guiding the learning process.

Next, a programed modification of the basic unit of instruction was developed, and is referred to hereafter as the "programed discovery" procedure. The programed discovery procedure attempted to prescribe the conditions under which "searching behavior" would be emitted by S in his pursuit of the instructional objective. Verbalized approval by E was used to reinforce searching behavior during the learning process. The primary difference from the free discovery procedure is that the teacher-learner interactions were prescribed in detail as were the sequences of learning experiences.

Finally, another program of instruction was developed which was designed to teach the same instructional objectives as the basic instructional unit but without employing the discovery method. This last variation is referred to in the experiment as the "programed guidance"

procedure. The programed guidance procedure duplicated the programed discovery procedure in every respect except that the experiences which were intended to foster searching behavior and the reinforcing events contingent upon such behavior were omitted.

The programed instructional procedures were group-paced and a teacher was present throughout instruction. In this regard they differed from conventional self-instructional procedures. Teacher interactions with the learners were prescribed in the programed discovery unit; however, the teacher relied heavily on tape-recorded instructions, overhead transparencies, slide projections, and an electronic classroom communication system in both programed discovery and programed guidance procedures. Using the classroom communication system, the teacher was able to provide "knowledge of results" to the learners individually through light signals, and also to determine immediately the proportion of the learners who responded correctly to each question or problem. The instructional system was named the Teaching Research Automated Classroom (TRAC). The TRAC facility is described in greater detail in Chapter II. It is sufficient to say at this point that, because many instructions could be given by tape recording and all auxiliary display and communication devices were also controlled by taped impulses, the teacher was free to interact with the learners either individually or on a group basis in an effort to teach a complex form of behavior (e.g., searching behavior) while the learners were otherwise learning subject-matter content by responding to stimulus materials presented automatically by the TRAC system.

The programed materials were developed so that a highly detailed documentation of the program design could be provided. They were

documented in such detail that particular items or groups of items could be traced from a flow chart which outlined the instructional design. Since the materials were so thoroughly documented, it was possible to change the original design in specific ways and then to modify the instructional materials accordingly without having to completely restructure the instructional program in its final form.

Experimental Design. A 2x3 design was employed in the experiment, with two teachers along one dimension and three instructional procedures along the other. Fifteen Ss were assigned to each cell, making a total of 90 Ss in the experiment.

Each experimental group was treated in the following manner:

First, Ss were tested to insure that they had the necessary prerequisite knowledge for the program of instruction. Following the pretesting, the students were oriented to the TRAC facility, and then taught by the appropriate procedure until each learner demonstrated by an appropriate criterion measure that he had attained the primary instructional objective (knowledge of the Distributive Law of arithmetic). The students were taught in groups, one hour daily for an average of 16 hours of instruction. All instruction took place in the TRAC facility.

Within 24 hours after completing instruction, each S was tested individually to determine how successfully he could apply the principles and procedures learned during instruction in answering questions concerning other general laws of arithmetic. At the same time S was questioned concerning his general reaction to the instructional procedure, and whether or not he employed the learned materials spontaneously out of class.

Within eight weeks after instruction, the Ss were given a post-test

consisting of problems similar to the ones used during the learning period. One-third of each group was administered the post-test three days after instruction, another third was given the post-test after two weeks, and the final third after six weeks.

Selection of Subjects. The Ss were selected from a group of approximately 125 fifth graders which constituted the entire fifth-grade population in two elementary schools in the vicinity of Monmouth, Oregon. Only students with an I.Q. equivalent of 90 or above and who were performing at grade level were selected for the experiment. Existing school records were used as a basis for screening the learners in terms of aptitude and achievement. Tests employed were the California Test of Mental Maturity and the Iowa Test of Educational Development.

The group of eligible learners were then screened further to insure that each had the prerequisite knowledge for the instructional program. A short paper-pencil test was devised for this purpose. Those who failed the test were eliminated from the experiment. The remaining group of eligible learners were assigned to experimental groups by a stratified procedure of random assignment in terms of sex and scholastic aptitude.

Since one of the schools was located approximately two miles from the location of the TRAC facility, it was necessary to assign Ss to the experimental groups by schools. One instructor taught all Ss from one school and the other instructor taught Ss selected from the other school. Although each experimental instructor taught approximately one half of the total number of Ss participating in the experiment, the number assigned to each group was slightly disproportionate. Each instructor taught each of the three experimental instructional procedures with

appropriate groups. Variance due to instructors was analyzed statistically.

Criterion Measures. The criterion measures employed in the experiment are described briefly below.

1. Pretest. The pretest consisted of questions and problems aimed at determining whether or not S could (a) identify a complete sentence, and (b) respond correctly to conventional arithmetic notation. These fifth-grade level abilities were required "entry behaviors" for each of the instructional procedures.

2. Instructional criterion measure. From a set of six "open sentences" (by the UICSM terminology and notation), S was asked to identify five out of the six examples correctly as open sentences which always would produce "true statements." The test required S to apply knowledge of the Distributive Law. Ss who made more than one error were given a brief review and then tested with a new set of examples. Learners who failed the second criterion test were given additional review and tested until they could identify three open sentences in succession correctly. Learners who failed to attain the criterion after the third review session were dropped from the experiment. Only four Ss were dropped because they failed to pass the criterion test.

3. Test of new learning. Each S was tested individually within 24 hours after instruction. The test of new learning consisted of three questions, each of which was designed to elicit a specific class of learned behaviors. In the first question, the learner was asked to look at a set of five examples of a general law of arithmetic and to determine whether or not they were all examples of the same law. If so, he was asked to write the general law which was represented using UICSM

notation. In the second question, the learner was reminded that the distributive pattern learned during instruction involved addition and multiplication, then he was asked whether or not there could be a distributive pattern employing multiplication and subtraction. The third question was the same as the first, except that a different general law was involved. As each learner attempted to answer the question, he was instructed to "think out loud" or to indicate what he was thinking by his scratch work. E employed a checklist to identify whether or not S employed certain prescribed behaviors labeled as "searching for patterns," "checking for exceptions to a possible pattern," "checking to see if statements are true or false," and "employing frames." The two experimental instructors were trained in the use of the observational technique, and their observations were checked on eight occasions by an observer who also was trained in the observational technique. There was 100 per cent agreement with the instructors on the specific behaviors checked independently by the observer as having been employed by each S at least once during the test.

4. Use of new knowledge out of class. At the same time the test of new learning was administered, S was asked three specific questions, and his answers were noted. The three questions were, (a) did he find it difficult to learn the Distributive Law, (b) how did he feel when he finally was able to identify a distributive pattern, and (c) did he employ his new knowledge out of class without instructions to do so? S was questioned by E until E was satisfied that S's answer could be categorized unequivocally. Once again there was total agreement by two independent observers on the proper recording of answers given by eight Ss.

5. Post-test of recall. A paper-pencil test consisting of problems similar to the ones used during instruction was administered to each subject in the small group within eight weeks following instruction. One third of each group was given the post-test three days after instruction, another third after two weeks, and the final third after six weeks. The post-test had been tried out previously on learners involved in the preliminary phases of the project when materials were being developed. The coefficient of reliability for the post-test was +.79 (obtained by split-half method, corrected with Spearman-Brown formula).

Results

To support the first hypothesis stated above, the evidence should show that groups taught by the programed guidance procedure complete instruction first, followed by the programed discovery and the free discovery procedure, in the order stated.

It should be remembered that each group was taught to the same criterion and instruction was terminated when every member of the group successfully passed the criterion test. Because instruction was group-paced, the number of sessions intervening the administration of the first criterion test and the last did not exceed two class sessions for any of the instructional groups. In most cases the terminating sessions were held successively on the same day. The actual frequency distributions are presented in Table 1 for inspection. While a statistical analysis of these data is possible, it was decided that the results would not be meaningful.

From the breakdown by treatment groups in Table 1, it may be seen that the programed discovery group actually required more time to complete instruction than either of the other groups. The programed discovery

Table 1

Number of Ss Completing Instruction by Sessions

Treatment	Session Number	Instructors		
		A	B	Both
Programed discovery	20	-	4	4
	21	10	4	14
	22	2	6	8
	23	4	-	4
Programed guidance	13	-	11	11
	14	12	1	13
	15	2	2	4
	16	2	-	2
Free discovery	10	8	-	8
	11	3	-	3
	12	3	9	12
	13	-	4	4
	14	-	3	3

group reached criterion after 20 - 23 sessions; the programed guidance groups after 13 - 16 sessions; and the free discovery group after 10 - 14 sessions. As would be expected, the variability in sessions (and in instructors) is greater for the free discovery group than it is for either of the two programed groups. The implications of these results are amplified below in the discussion section.

Results pertaining to hypothesis 2a. The second hypothesis is stated in two parts, 2a and 2b. If part 2a were true, Ss in the programed discovery and free discovery groups would have used what they learned spontaneously (i.e., without instructions to do so "out of school") more frequently than learners in the programed guidance group. Evidence pertaining to the learners' use of the learned materials out of class is summarized in Table 2, which also includes information pertaining to the learners' responses to other questions. After instruction, each learner was first asked whether or not he felt it was difficult to learn the distributive pattern. It was possible to classify nearly every response either in the affirmative or negative. Chi-square analysis of the distribution of responses to the first question indicates that observed differences are reliable when compared against an expected frequency of equal row values ($p < .05$).

Each learner next was asked how he felt when he first identified the distributive pattern successfully. Reactions to the second question were grouped in three categories as indicated in Table 2. Chi-square analysis of differences in the distribution of reactions to the second question indicated that the differences are not reliable.

The responses to the third question in Table 2 are those which pertain directly to hypothesis 2a. Each S was asked whether he employed

Table 2

Responses to Questions Related to Instruction and Use of Learned Information

Questions		Progr. Discovery	Progr. Guidance	Free Discovery
1. Was instruction (learning) difficult?				
Answer[b]	Yes	18	21	27
a	No	11	8	3
a	Other	1	1	0
2. How did you feel when you first learned (distributive pattern)?				
Answer:	(2.1) No reaction	3	10	5
a	(2.2) Relieved Stupid Better	16	9	11
a	(2.3) "Like telling" Excited Happy Surprised Proud -etc.-	11	10	14
a	(2.4) Anxious	0	1	0
3. Did you use (learned info.) after class?				
Answer:	Yes	15	18	21
	No	15	12	9

[a] Combined for chi-square analysis

[b] Statistically significant ($p < .05$)

the learned material out of class without instructions to do so, then was asked a number of questions concerning the details of using or not using the information to the extent necessary for E to classify the learner's response in either the affirmative or negative category. Differences in the distribution of responses to the third question also are not statistically significant. These results are also amplified in the discussion section below.

Results pertaining to hypothesis 2b. A total score of 20 correct answers was possible on the recall test which was used to provide evidence pertaining to hypothesis 2b above. If true, the recall test data would indicate that both the programed discovery and free discovery groups were superior to the programed guidance group. The mean test scores for each group are summarized in Table 3; and Tables 4 and 5 summarize the analysis of variance.

In Table 5 the use of a partial sample was required to account for disproportionality in the total sample. The disproportionality was the result of the two teachers not having an equal number of learners in their instructional groups. In the second analysis the main effects for treatments and for test periods were designated as "fixed" variables because neither treatments nor test periods could be considered representative of all others in their own category. The main effects for instructors were designated as "random" because the two instructors were representative of any experienced elementary teacher who could have been employed. This rationale determined the selection of denominators for the F-test (Green & Lukey, 1960).

As is indicated, the observed differences between groups and between subgroups administered the same tests at different time intervals

Table 3

Mean Recall Test Scores

Test Period	Progr. Discovery	Progr. Guidance	Free Discovery
3 days	11.10	12.70	13.80
2 weeks	15.00	12.20	13.50
6 weeks	12.78	14.00	13.20
All periods	13.03	12.97	13.50

Table 4

Recall Test: Analysis of Variance Summary
Using Full Sample (n = 90)

Source	df	ss	ms	f
Treatments (T)	2	5.067	2.533	.209
Test periods (P)	2	19.127	9.564	.787
TP	4	80.450	20.113	1.656
Within	81	983.856	12.146	
Total	89	1088.500		

Table 5

Recall Test: Analysis of Variance Summary
Using Partial Sample (n = 66)

Source	df	ss	ms	Denom.	F
Treatments (T)	2	26.293	13.137	12.864	1.021
Periods (P)	2	12.123	6.062	18.179	.333
Instructors (I)	1	26.727	26.727	11.813	2.263
TP	4	61.839	15.460	17.433	.886
TI	2	25.727	12.864	11.813	1.089
PI	2	36.357	18.179	11.813	1.539
TPC	4	69.772	17.443	11.813	1.477
Within	48	567.00	11.813		
Total	65	825.818			

are not reliable. The learners in each group apparently retained what they learned as well after six weeks as they did after three days.

Additional data pertaining to hypothesis 2b. It may be recalled that within 24 hours after instruction, each learner was taken aside individually and asked to think out loud as he attempted to answer three problem questions. E observed the learner and marked a checklist whenever he observed the learner employing prescribed behaviors labeled "searching for patterns," "checking for exceptions to patterns," "checking for true-false statements," and "trying frames." These behaviors were identified as being representative of techniques of independent discovery and problem solving which each instructional procedure was designed to foster, but by different procedures of instruction. In accordance with hypothesis 2a, these data should indicate a higher frequency of observed discovery and problem-solving behavior in the discovery groups than in the programed guidance group. The chi-square analysis indicates that the observed differences in the frequency distributions are reliable only in the first category of "searching for patterns." As is indicated in Table 6, the programed discovery group evidenced a tendency to search for patterns less frequently than the discovery group and the programed guidance group was intermediate in this respect.

Discussion

Because the evidence from the present research effort pertains to a particular variation of learning by discovery, and because the technique of instructional programing also is unique in the present case, it would be unwarranted to generalize from the present findings to discovery methods or programed instruction in general. At the same time,

Table 6

Test of New Learning: Observed Techniques of Discovery and Problem-solving

Techniques		Progr. Discovery	Progr. Guidance	Free Discovery
1. Search for patterns:[a]	Yes	17	21	27
	No	13	9	3
2. Check for exception to pattern:	Yes	12	13	11
	No	18	17	19
3. Use frames:	Yes	21	20	22
	No	9	10	8
4. Check for T-F statements:	Yes	28	30	30
	No	2	0	0

[a] Statistically significant ($p < .02$)

the particular examples of instructional programs employed in the present experiment were very carefully developed and are thoroughly documented, so the results should not be treated lightly, particularly as they bear on operant conditioning as a learning model for searching behavior.

The efficiency of programed learning. In the first place, it is evident that when instructional procedures are designed and developed systematically, the outcome is not necessarily a time-saving learning experience. In the present experiment, the programed groups required no less time than the free discovery group which was not programed. If anything, the group taught by conventional instructional techniques required less time to reach criterion.

The relative speed with which the free discovery group completed instruction may reflect the fact that the classroom instructors involved had acquired increased skill in teaching the particular unit involved after having taught two previous groups by the programed procedures. The experimental design was not counterbalanced with respect to the order in which the procedures were taught.

Variability in learning rate may be expected to be greater for groups taught by nonprogramed methods, but this added flexibility may have been a decided advantage in the present case. One danger involved when instructors are not following a prescribed sequence of instruction is that important steps in the learning process will be passed over before every learner has achieved criterion, or omitted completely. In the present experiment, because the instructors had an intimate knowledge of the sequence of instructional objectives which served as a framework for the programed procedures, the danger that they would omit

entire sections was minimized.

In short, it may be that the instructors employing the "free discovery" procedure were more than usually efficient because they were utilizing highly refined instructional materials and an established instructional strategy. Since they were skilled instructors, they may have been more effective in pacing the learning of the groups taught by the free discovery method than was possible by following a rigidly prescribed regimen.

Effectiveness of the operant conditioning model. It was reported above that Ss in the free discovery group employed searching behavior more frequently than did Ss in the programed guidance group; and the programed discovery procedure was least effective in teaching Ss to search for patterns (see Table 6). Since opportunities for Ss to "search" were systematically eliminated from the programed guidance procedure and they were "built in" to both discovery procedures, the evidence does not support the hypothesis that Ss learned to search for patterns by operant conditioning.

The fact that neither discovery group employed the learned information more frequently after instruction than did the programed guidance group suggests that this writer's previous findings (Kersh, 1958, 1962) may be relatively unique to the particular instructional setting or instructional materials employed in the earlier experiments.

Once again, we have evidence which indicates the complexity of the instructional process generally referred to as "learning by discovery." Discovery learning as an identifying label may be convenient for pedagogical use, but it has absolutely no value in research as an identifier of a specific learning strategy.

The superiority of the free-discovery procedure. The fact that the free discovery group tended to employ the behavior called "searching for patterns" more frequently than learners in either of the other two groups is perhaps the most significant finding of the entire research effort. This one finding indicates that something in the learning experience of those in the free discovery group was different from that which was programed in the programed discovery, and that perhaps the programed guidance and free discovery procedures have more in common than is evident. Although the learning experience for the programed groups was carefully documented, the details of the instructional process for the free discovery group were not. Consequently, we know what it is that does not foster searching behavior, but we can only presume what might have been unique about the experience provided the learners in the free discovery group.

There are a number of possible explanations for this last finding. Since the free discovery procedure was the last one employed by both experimental instructors, it is easy to conclude that they might have gained much from their experience with the previous two instructional techniques. It is necessary to remind oneself that the programed discovery and programed guidance groups were carefully controlled with respect to the kind of exploratory behavior which was allowed and the reinforcing stimuli contingent thereon. If there were any credence to the possibility that the free discovery procedure was in reality simply a more flexible "programed discovery" procedure, the data would have suggested a trend from the one extreme of programed guidance to the other of free discovery with the programed discovery procedure falling somewhere in between in effectiveness. Consequently, it is more reasonable

to conclude, as has been suggested above, that the free discovery procedure (and perhaps the programed guidance procedure) represents some uniquely different learning strategy.

A clue may be in the finding that a larger proportion of the free discovery group reported that the learning was "difficult." Exactly what their response means is open to conjecture, but somehow it "fits" that learners who may have become deeply engrossed in the learning process and who have experienced the excitement of the search, regardless of its outcome, should report that the experience was a difficult one. This notion is in accord with the concept of "competence motivation," developed by White (1959). According to White, when human beings engage in an activity that is exploratory in nature, involves manipulation, and produces novel results, they may be motivated to continue the activity by an urge to become competent or proficient. An important aspect of White's notion is that the rewarding feature of competence motivation stems from the arousal and maintaining of activity, not from the completion of the act. In White's own words:

> "Because there is no consummatory climax, satisfaction has to be seen as lying in a considerable series of transactions, in a trend of behavior rather than a goal that is achieved. It is difficult to make the word "satisfaction" have this connotation, and we shall do well to replace it by "a feeling of efficacy" when attempting to indicate the subjective and affective side of effectance." (White, 1959, p. 322)

Perhaps the searching behavior observed during the test of new learning was not learned during the instructional period. Perhaps all learners were equally capable of "searching" prior to the experiment and

it was aroused in a higher proportion of the learners in the free discovery group simply because the circumstances under which they learned permitted them to explore alternatives more freely. In addition, they were more free to interact with the teacher and other learners in the free discovery situation--and in an experimental setting where external rewards (grades) were not emphasized. Although these were precisely the circumstances which the programed discovery procedure attempted to prescribe, the very fact that the instructional procedure was prescribed did, in fact, restrict spontaneous learner behavior. This small difference in teaching strategy may have been all-important.

It remains to be asked why the programed guidance group was intermediate with respect to the incidence of searching behavior. It would be more reasonable to expect that the programed discovery group would be intermediate because there was more opportunity in the programed discovery procedure for exploratory activity. Opportunities for exploration were programed out of the programed guidance group as effectively as possible.

However, the novelty of the materials and new ideas about number relationships may have been more influential in the programed guidance groups. White also attributes competence motivation to novelty (White, 1959, p.322). Reportedly, the final phases of instruction had a palling effect on the programed discovery group because Ss were required to keep up with their regular school work during their participation in the experiment. After 21 days, the extra burden of homework was becoming tiresome. By contrast, the programed guidance group progressed more rapidly and finished after approximately 14 days. Consequently, the novelty of working in the TRAC facility and learning some intriguing

information about numbers may have had the effect of arousing and maintaining their interest in the activity.

Conclusions

From the evidence obtained from the present experiment, it may be concluded that the desirable learning outcomes which sometimes result from "learning by discovery" cannot be adequately explained in terms of operant conditioning. Instead, the desirable learning outcomes may as frequently result from a learning procedure which delimits searching behavior and reinforcement (e.g., programed guidance procedure).

It is possible that searching behavior may not be "learned" from a discovery-type instructional experience at all. A tendency for learners to continue searching for answers after class may have little to do with a reinforcing "climax" in learning when a new relationship of ideas or objects is "discovered." Nor is such behavior necessarily related to verbal reinforcement (praise) from a teacher when the learners are engaged in searching behavior during instruction. Perhaps it does have something to do with the learner's tendency to feel more competent or proficient with numbers and to be intrigued by the novelty of the experience, after having been guided through a successful exploration of new ideas about numbers and number patterns.

II. Programing Complex Learning Processes [1]

The experience gained in developing the instructional materials for the experiment has provided an instructional design procedure which may be considered more significant than the research evidence obtained. If further developed, the procedure could stimulate further research on problems of instructional design beyond the limitations of existing techniques and procedures. Present indications are that research on instructional processes will continue to move into the area of instructional theory and strategy, and will stress increasingly more the attainment of instructional objectives as contrasted with gross effects of relatively unspecified instructional "methods." This direction in research is indicated by the writings of Bruner (1961), Gage (1963) and Gagné (1962), to name a few. Employing a programing procedure such as the one described in the present chapter, it may be possible to develop experimental materials which can be modified with such precision that comparisons can be made between different instructional strategies with confidence that the observed behavioral outcomes are consequences of specific instructional variables. With such materials available, avenues may be opened for exploring old research problems such as the whole-part, inductive-deductive, and retroactive-proactive inhibition problems in a completely new research setting and with greater promise

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[1] The contents of this chapter were reported earlier in a paper read at the Invitational Working Conference on Programed Instruction, National Education Association, Washington, D. C., March 24-26, 1963. The conference paper was later expanded into a chapter prepared for R. Glaser (Ed.), Teaching Machines and Programed Instruction: Data and Directions. (Washington, D. C.: National Education Association, in press.)

for solution.

In this chapter, the procedure employed in the present project will be outlined and in Chapter III some implications from the present project will be made for further research on instructional design procedures.

Compounding Instructional Objectives

Public school teachers today do not often limit themselves to teaching one thing at a time. If they wish to teach some computational skill in arithmetic, for instance, they also concern themselves with such "by-products" of learning as the attitudes of their students towards arithmetic. If they wish to teach theory of combustion, they may also concern themselves with "understanding scientific method" and "skill in problem-solving." Even if teachers were satisfied to deal with a single objective at a time, psychologists would remind them that they must not only consider the objective from the standpoint of immediate learning, but also should give consideration to the maintenance and subsequent use (transfer) of the new learning.

Hereafter, the label "simple objective" will be used to designate only instructional objectives which can be attained by self-instructional techniques, i.e., without direct guidance. "Complex objectives" will designate only those objectives which are difficult, if not impossible, to attain without direct guidance or help from another person. Assistance from another person may be required in the attainment of complex objectives for any one or more of the following reasons:

1. The required behavior cannot be identified by machine processes presently available, or by the learner himself, without previous instruction.

2. The required behavior cannot be reliably elicited except through direct or indirect communication with another person who is capable of identifying the required behavior once it has been elicited.

3. The learner cannot determine that he is making progress toward the instructional objective by independently comparing his own behavior against a behavioral standard or model.

It is probable that simple objectives will usually include knowledge of facts, concepts, principles, and psycho-motor skills. Complex objectives will usually involve patterns of behavior which occur at unpredictable intervals and reflect "mediational" processes, e.g., problem solving, self-activated goal-seeking behavior (motivation, interest), flexible thinking, hypothesis formation, and transfer.

It may be said that most educational objectives involve more than one simple or complex objective. When so, they are "compounded." Although techniques of self-instructional programing are infinitely more precise than conventional techniques, they are presently limited to simple objectives.

A new procedure for programing instruction was required for purposes of this present project--one which would incorporate the techniques employed in developing self-instructional programs in the design and development of procedures for attaining both simple and complex objectives.

It was found in the present project that to attain both simple and complex objectives concurrently requires the capabilities of an automated classroom system. Otherwise, the teacher is taxed beyond his ability in attempting to control the experiences of the learners. To reduce the burden on the teacher, and to allow him to concentrate on

those activities which require human guidance, a systematically developed set of instructional materials and validated procedures must be available. The complexity of designing and developing an instructional unit which teaches more than one objective simultaneously far exceeds that of self-instructional programing. The programer must concern himself with two or more processes which will be in operation at once, in the same fashion that a composer of music develops a symphonic score.

The essential characteristics of the methodology outlined below are the following:

1. It provides a notation and charting technique with which the programer can prepare in advance a detailed outline of the learning experience in terms of practice and reinforcement schedules, branching criteria, and related characteristics, without attending to the specifics of frame-writing.

2. It outlines a procedure for preparing more than one basic program aimed at a simple objective together with programs for attaining complex objectives, if necessary. It makes it possible for the programer to keep the basic program intact while changing that portion which pertains to a particular objective. In this way, different processes of learning can be employed simultaneously in a single program, or a single program can be systematically altered for purposes of research and development.

3. It enables the programer to deal separately with problems of program design, frame-writing, and materials development so that these operations can be accomplished by different individuals concurrently.

In short, the procedure makes it possible for an expert in human learning to prepare in advance an outline of the learning process

independently of the programer and materials development specialist, just as the classroom teacher today prepares a lesson plan with the general specifications for source materials which can then be located or developed separately. Similarly, the special competencies required of a program writer can and perhaps should be distinguished from those required of the materials development specialist. By analogy, the item writer for a standardized test is not required to develop the format of the test, to prepare the finished line drawings or diagrams that may be involved, or necessarily to try out the test materials in preparation for their revision.

The procedure outlined below is referred to as the "TRAC procedure," because it was developed in the Teaching Research Automated Classroom (TRAC). TRAC is a part of the Teaching Research Laboratory located on the campus of Oregon College of Education. TRAC evolved from the present project effort in accordance with the particular instructional requirements involved. It was a requirement, for instance, that instruction be group-paced because the research design employed the UICSM classroom instructional technique as a model. Furthermore, it was a requirement in the present research that as many instructional tasks as possible be performed through the use of autoinstructional techniques in order that the teacher could effectively seek out and reinforce desirable behavior patterns as they might appear in connection with discovery exercises and group discussions. In effect, as many of the simple instructional objectives as possible were taught by purely autoinstructional techniques, and the attainment of complex instructional objectives was guided by the teacher.

The TRAC facility is described in more detail in another publication

(Kersh, 1964). Briefly, it consists of three instructional systems to provide the teacher with a capability for providing individualized feedback to students through light signals, for collating student responses to a single stimulus question or problem, while remotely controlling a motion picture projector, slide projector, overhead transparency projector (all on a single rear-projection screen), and for operating a tape-recorder and voice amplifier. The Edling Teacher's Console, one of the three systems comprising TRAC, is a desk unit with overhead screen for the various projectors housed in the desk. The second system, the Teletest Communication System, consists of response units at each student position and a small teacher's console on the desk unit (Edling Teacher's Console). The third system, the EDEX, is a system built around a dual-track tape recorder. The EDEX serves as a control center for each of the other two systems. Instructions to the students in the classroom are recorded on one track of the tape-recorder unit, and impulses on the other track activate switches which operate the Teletest Communication System and the projectors located in the Edling Teacher's Console.

Individualized feedback is provided to the learners through the communications system by colored lights in the student response units. The students respond by pushing buttons in their response unit and see a red light if they make an incorrect response, and a green light if they make a correct response. The proportion of correct responses made by the class at each step of the way is indicated by a meter in the small teacher's console. The instructor refers to the meter frequently as a basis for making branching decisions. This use of the Teletest Communication System is described in greater detail in the sections which follow.

As is the case in most technological developments, the TRAC procedure

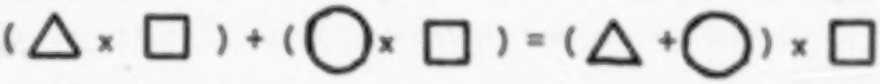
consists of a new combination of existing procedures. The first step in the procedure follows the example of Gagné (1962), and subsequent steps are applications of already familiar flow-charting methods employed in computer programing.

The following steps outline the procedure used in the development of the instructional unit for the present project. The instructional unit employed the principles of instruction, terminology, and notation employed in the UICSM curriculum, but was designed for fifth graders.

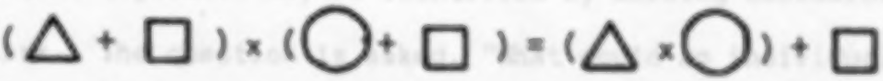
Step 1. Specification of Objectives in Terms of Both Content and Process.

In the preparation of the instructional materials for the research project, consideration was given not only to the content objective (knowledge of the Distributive Law), but also to the attainment of some rather complex behaviors which are frequently associated with problem-solving and discovery processes. These objectives were handled independently and were written as specific instructional objectives. Specifically, the instructional program was planned and developed so that the learner, when through, would be able to do the following:

1. Specify that numerals put into the frames will always make this "open sentence" true:



2. Specify that numerals put into the frames will <u>not</u> always make this open sentence true:



3. Without instructions from the teacher (T), to use the Distributive Law or related information after the formal learning period.

4. Without instructions from T, in a task employing a different principle and new examples, to employ the same discovery processes

taught in the original learning.

5. After instruction, to correctly identify examples of the Distributive Law from among examples of other numerical operations.

6. After instruction, to correctly employ the Distributive Law in the regrouping of numerals in mathematical sentences to form simpler sentences.

Note that the objectives also serve as criteria for learning. For example, the teacher may point to a mathematical statement such as that indicated in Objectives 1 or 2 and ask, "If you fill in the frames with numbers, will this sentence always produce a true statement?" If the learner can give the correct answer, we presume that he knows the Distributive Law. The third objective specified behavior which is indicative of motivation; the fourth indicates transfer of "discovery processes." The last two objectives indicate the learner's ability to remember and apply what he learned.

Step 2. Preparation of a Hierarchy of Subordinate Facts and Processes.

This technique is modeled after Gagné (1962). The procedure differs from Gagné's in that there are multiple objectives which involve the acquisition of complex behavioral processes as well as the acquisition of knowledge.

According to Gagné, the tasks to be learned in the acquisition of a specific content objective may be identified by working backwards from the final task. The question is asked, "What would an individual have to know in order to perform this task successfully?" The answer to this question reveals subordinate knowledge which the individual must know in order to obtain the ultimate objective. The subordinate knowledge is presumably simpler and usually more general. This subordinate knowledge

is again subjected to the question, "What does one have to know in order to achieve this?" And still more subordinate knowledge is revealed in the answer.

By continuing this questioning procedure and working backwards from the ultimate objective, a hierarchy of subordinate knowledge is established. In the end, the final content objective is seen to rest on a framework of subordinate knowledge which becomes increasingly more simple and more general.

So much for the acquisition of knowledge. What about the acquisition of complex discovery processes (e.g., Objective 4, above) and the intentional increase of motivational effects (Objective 3)? Again, Gagné deals with such processes as distinguished from knowledge. He does so by manipulating the programed "instructions" which determine the sequence of experiences, the format of each experience, and the criteria for determining the learner's route at choice points. Gagné has reported attempts to study the effects of instructions designed to insure high recallability of subordinate knowledge and to guide the learner's thinking (Gagné, 1962, p. 361).

The essential change which is made in Gagné's method is to clearly identify the specific "process objectives" which one wishes to attain and to deal with them independently of (but concurrently with) the "content objectives." The subordinate knowledge which must be acquired is identified by asking what the learner must <u>know</u> (after Gagné), and the subordinate learning processes are identified by asking what the learner must <u>do</u>.

Consider, for example, the six content and process objectives written for the Distributive Law. The breakdown of these six objectives

into subordinate facts and processes is shown in Figure 1. Some of the subordinate facts and processes for the six major objectives are combined as under Objectives 1, 2, and 4. The other objectives in this case must be outlined separately. For now, the reader's attention is directed to the breakdown for Objective 3. It requires that the learner generate enough interest in the Distributive Law to use it after the formal learning period without instructions to do so. What must the learner do to develop this interest? The answer is written in the four smaller boxes labeled 18, 19, 20, and 21. These subordinate process statements specify that the learner should employ subordinate knowledge in discovering higher-level tasks repeatedly; with knowledge of results; on a schedule in which the teacher's instructions are gradually withdrawn; and with approval provided intermittently, regardless of the learner's success or failure. There is nothing by way of a hierarchal arrangement forthcoming; however, the rather complex statement of process is broken down into four separate subordinate processes, each corresponding to the specific qualifying statements following the stem.

Now locate Objective 4, the "transfer of discovery process" objective in Figure 1. It is combined with the "content objectives" (Objectives 1 and 2). Clearly it is a higher level of learning than the content objectives, and probably should be classed as a "learning set," but it rests on a framework of specific knowledge as indicated. Not clearly indicated in the broad outline is the learning set. The more detailed design required the learner to employ specific discovery techniques in learning, to be able to identify these specific processes, and to recognize that they may be transferred. Much of the discovery practice was effectively accomplished in the attainment of Objective 3,

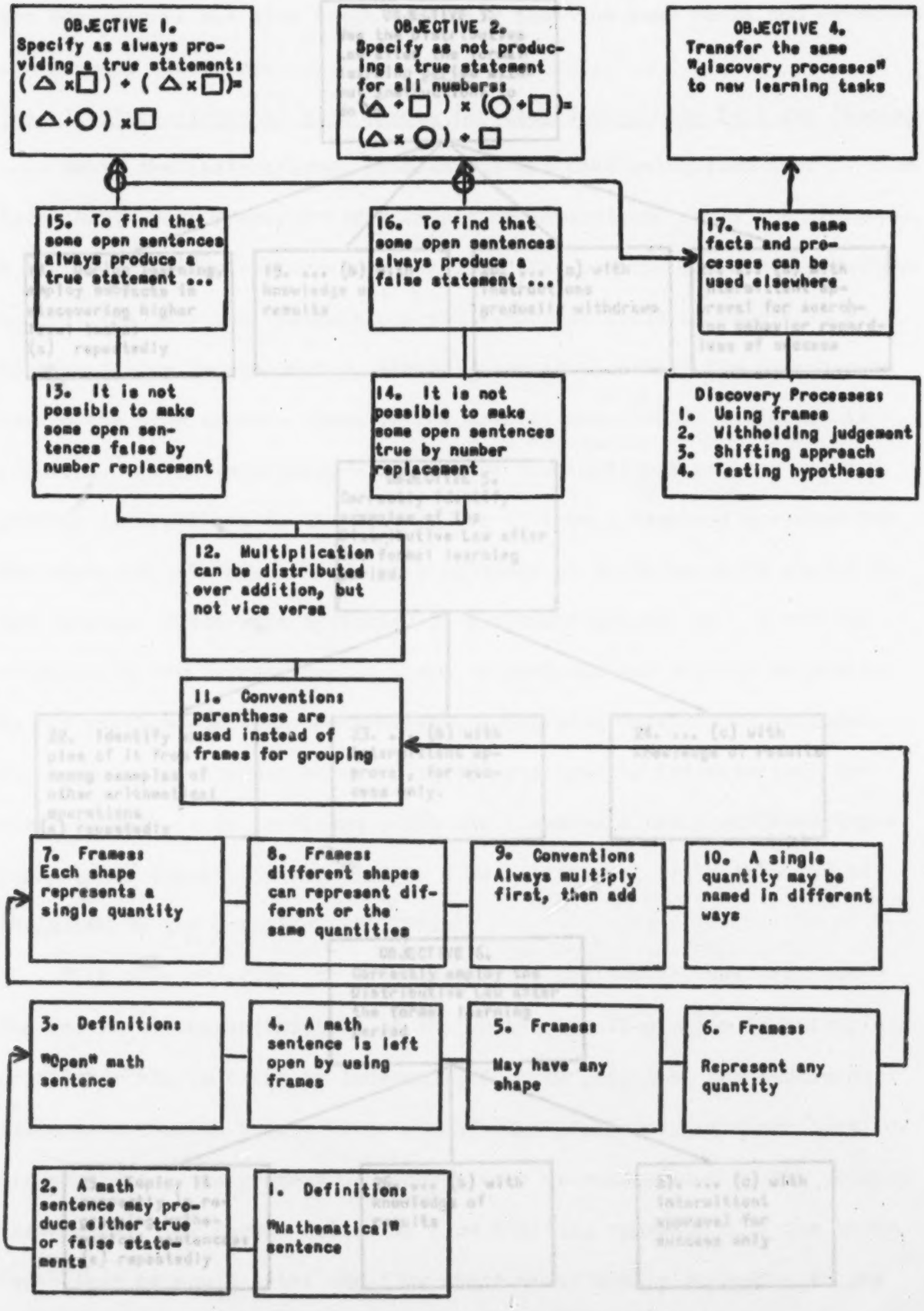
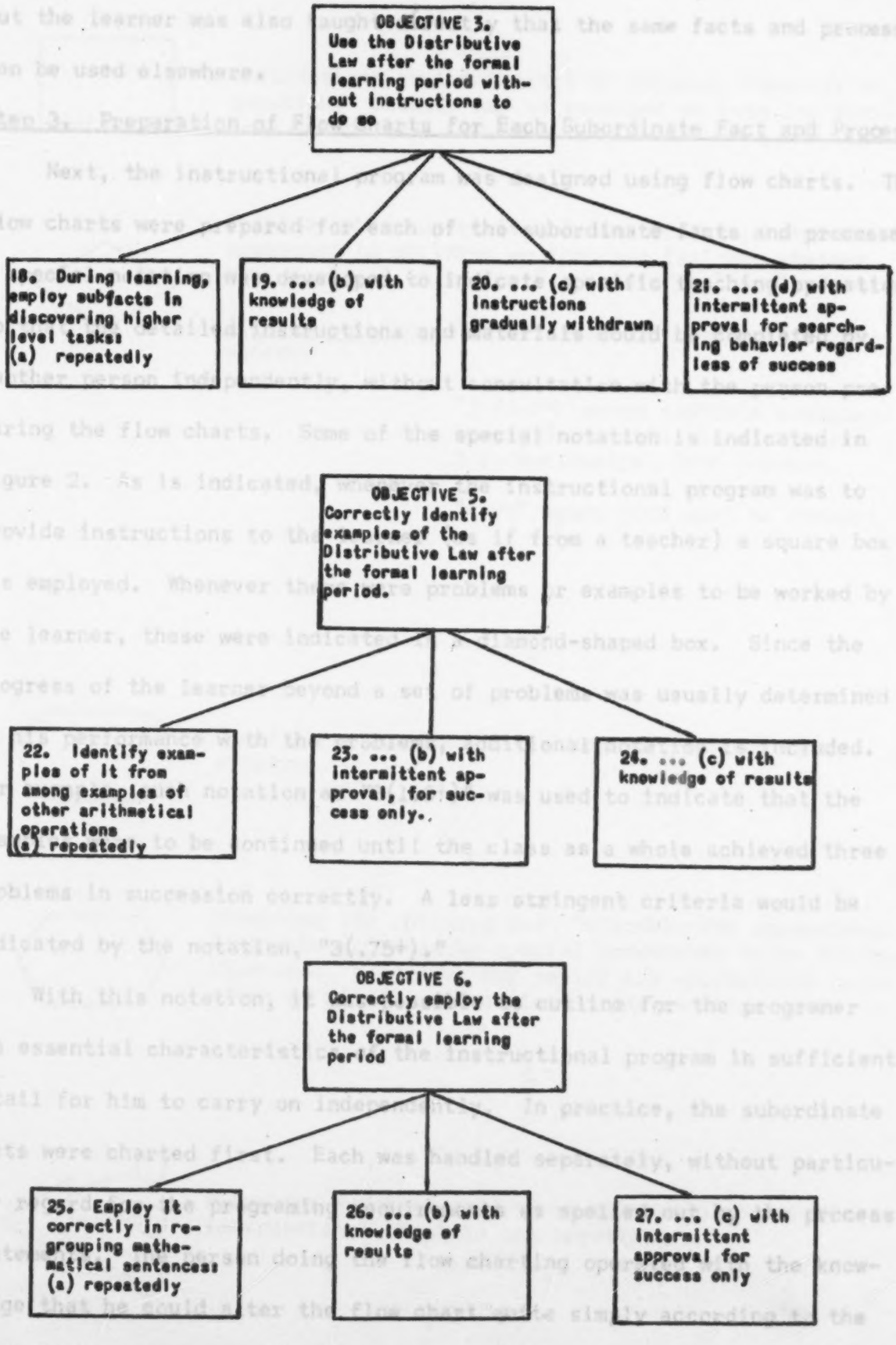

OBJECTIVE 1.
Specify as always providing a true statement: (△×□) + (△×□)= (△+○)×□
OBJECTIVE 2.
Specify as not producing a true statement for all numbers: (△+□)×(○+□)= (△×○)+□
OBJECTIVE 4.
Transfer the same "discovery processes" to new learning tasks
15. To find that some open sentences always produce a true statement ...
16. To find that some open sentences always produce a false statement ...
17. These same facts and processes can be used elsewhere
13. It is not possible to make some open sentences false by number replacement
14. It is not possible to make some open sentences true by number replacement
Discovery Processes:
1. Using frames
2. Withholding judgement
3. Shifting approach
4. Testing hypotheses
12. Multiplication can be distributed over addition, but not vice versa
11. Conventions: parenthese are used instead of frames for grouping
7. Frames: Each shape represents a single quantity
8. Frames: different shapes can represent different or the same quantities
9. Conventions: Always multiply first, then add
10. A single quantity may be named in different ways
3. Definitions: "Open" math sentence
4. A math sentence is left open by using frames
5. Frames: May have any shape
6. Frames: Represent any quantity
2. A math sentence may produce either true or false statements
1. Definitions: "Mathematical" sentence

Figure 1. Hierarchy of subordinate facts and processes.


OBJECTIVE 3.
Use the Distributive Law after the formal learning period without instructions to do so
18. During learning, employ subfacts in discovering higher level tasks:
(a) repeatedly
19. ... (b) with knowledge of results
20. ... (c) with instructions gradually withdrawn
21. ... (d) with intermittent approval for searching behavior regardless of success
OBJECTIVE 5.
Correctly identify examples of the Distributive Law after the formal learning period.
22. Identify examples of it from among examples of other arithmetical operations
(a) repeatedly
23. ... (b) with intermittent approval, for success only.
24. ... (c) with knowledge of results
OBJECTIVE 6.
Correctly employ the Distributive Law after the formal learning period
25. Employ it correctly in regrouping mathematical sentences:
(a) repeatedly
26. ... (b) with knowledge of results
27. ... (c) with intermittent approval for success only

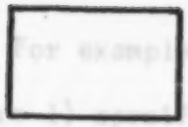
(Figure 1. continued. Hierarchy of subordinate facts and processes.)

but the learner was also taught directly that the same facts and processes can be used elsewhere.

Step 3. Preparation of Flow Charts for Each Subordinate Fact and Process.

Next, the instructional program was designed using flow charts. The flow charts were prepared for each of the subordinate facts and processes. A special notation was developed to indicate specific teaching operations so that the detailed instructions and materials could be completed by another person independently, without consultation with the person preparing the flow charts. Some of the special notation is indicated in Figure 2. As is indicated, whenever the instructional program was to provide instructions to the learner (as if from a teacher) a square box was employed. Whenever there were problems or examples to be worked by the learner, these were indicated in a diamond-shaped box. Since the progress of the learner beyond a set of problems was usually determined by his performance with the problems, additional notation is included. For example, such notation as "3(1.0+)" was used to indicate that the examples were to be continued until the class as a whole achieved three problems in succession correctly. A less stringent criteria would be indicated by the notation, "3(.75+)."

With this notation, it was possible to outline for the programer the essential characteristics of the instructional program in sufficient detail for him to carry on independently. In practice, the subordinate facts were charted first. Each was handled separately, without particular regard for the programing requirements as spelled out by the process statements. The person doing the flow charting operated with the knowledge that he could alter the flow chart quite simply according to the subordinate process requirements after he had prepared the outlines for



Instructions to the teacher to explain, identify or question. Usually may be recorded on tape for playback to children.

Problems or examples (e.g.) for children. Must be presented to children so they can indicate whether they "solved" it or "not", answer "yes" or "no", etc.

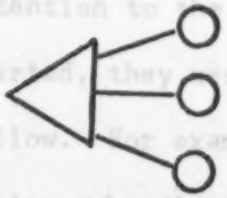
Special notation: ".95 +" means 95% must get correct answer.

"3 (1.0+)" means continue examples or problems until class achieves 3 in succession, 100% correct.

"1.0+" means 100% must be correct.

Special instructions for obtaining feedback from children.

Something the children must "discover for themselves. Sometimes followed by special procedures to be followed. Otherwise, programer may employ any appropriate technique of non-directive (inductive) teaching.



Branching junction used where sequential order of instructional steps is not important.

Figure 2. Examples of flow chart notation

each of the subordinate facts.

For example, sub-fact 10 in the list of subordinate objectives (see Figure 1) specifies that the learner know that a single quantity may be named in many different ways (e.g., the quantity 10 may be referred to as "5 + 5," "6 + 4," or simply as "10"). Without regard for any of the process statements, and following an established rule-example technique, the flow chart could be drawn first as shown in Figure 3. The flow chart should be read from left to right starting with circle 10 (sub-fact 10).

The first box indicates to the programer that the instruction should start with an example concerning a boy with several names. The next box indicates that, by analogy, the rule is to be established that a quantity such as 10 may be referred to in a number of different ways including "5 + 5," and "6 + 4." At circle 10.1 (simply a location point or connecting link), the flow chart moves to a diamond-shaped frame which indicates that the program should follow with a test. The notation "3(1.0+)" specifies that the learner should continue with the test until he achieves three examples in succession correctly. The notation "5±" specifies that, should the learner fail to achieve the criterion after five examples, the program should return him to a new explanation of sub-fact 10 and then test him again. Circle 11 indicates that when the learner passes the test he is to go to sub-fact 11.

After the sub-facts were charted, the program "designer" turned his attention to the subordinate process statements. Instead of being flow charted, they were reduced to specific instructions for the programer to follow. For example, sub-process 18 indicates that the learner should employ subordinate knowledge repeatedly during the learning process in discovering (ascertaining) higher-level tasks. The specific instructions

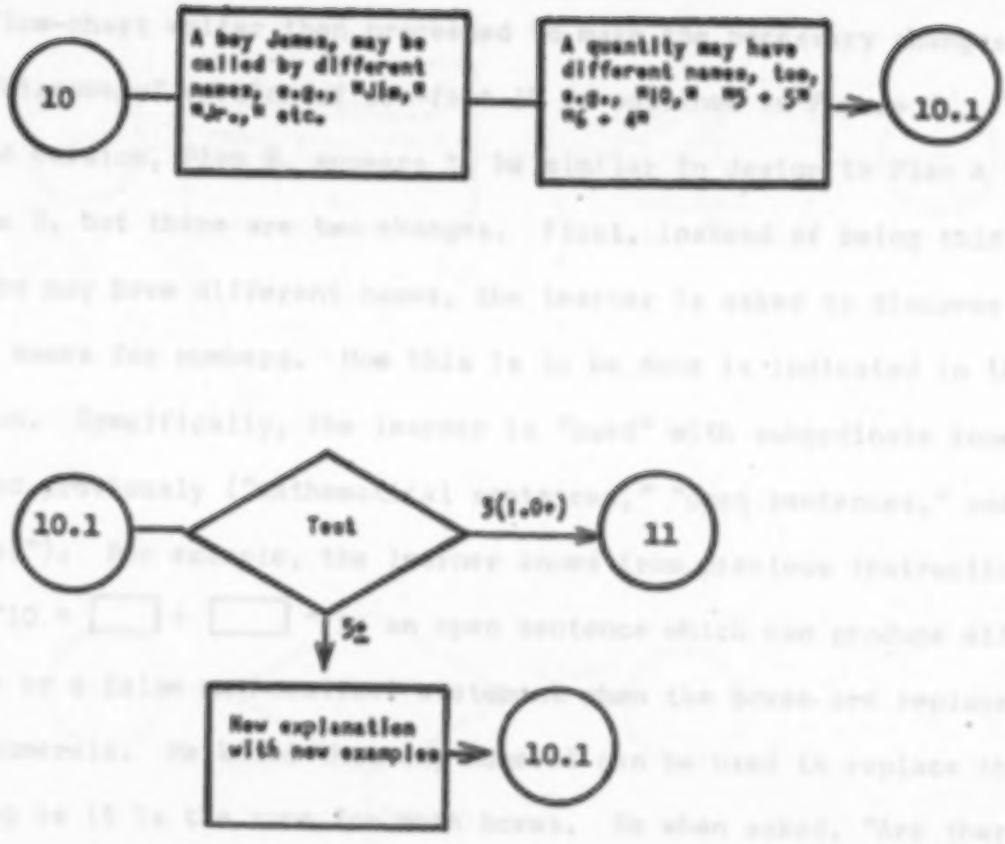
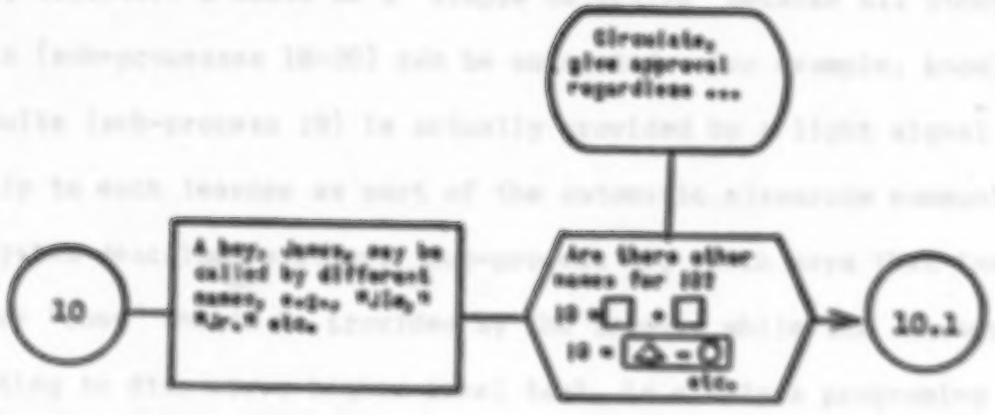


Figure 3. Plan A for sub-fact 10, "A single quantity may be written different ways."

tell the programer to identify every sub-fact in the instructional process which may be "discovered" using previously learned facts and to rewrite them if necessary so that the learner is required to do so. It happens that sub-fact 10, charted above, is one which can be "discovered" and, written as it is in Figure 3, it needs to be rewritten.

Having identified sub-fact 10 among others that needed rewriting, the flow-chart writer then proceeded to make the necessary changes. The new "discovery" version of sub-fact 10 is outlined in Figure 4. The second version, Plan B, appears to be similar in design to Plan A in Figure 3, but there are two changes. First, instead of being told that numbers may have different names, the learner is asked to discover some other names for numbers. How this is to be done is indicated in the hexagon. Specifically, the learner is "cued" with subordinate knowledge learned previously ("mathematical sentences," "open sentences," and "frames"). For example, the learner knows from previous instruction that "10 = $\square$ + $\square$ " is an open sentence which can produce either a true or a false mathematical statement when the boxes are replaced with numerals. He knows that any numeral can be used to replace the box so long as it is the same for both boxes. So when asked, "Are there names for ten?" and then shown open sentences such as those in the hexagon (Figure 4), the learner may more easily ascertain the correct answer.

Second, in accordance with sub-process 21 (Figure 1), the flow-chart indicates that the teacher is performing a task which cannot be automated. The teacher must discriminate between student behaviors which are indicative of "problem solving" or "searching" and those which indicate that a learner is otherwise occupied. Once these complex behaviors have been specified, it is not difficult for a classroom teacher


Circulate, give approval regardless ...
10
A boy, James, may be called by different names, e.g., "Jim," "Mr." etc.
Are there other names for 10?
10 = □ · □
10 = △ · ○
etc.
10.1

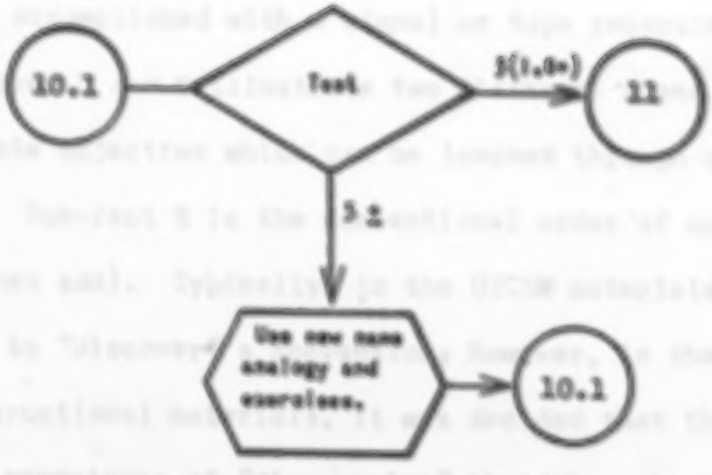


Figure 4. Plan B for sub-fact 10, "A single quantity may be written in different ways."

to identify them.

Because a human observer is required at this point, Objective 3 is, by definition, a "complex objective." If sub-process 21 were not involved, Objective 3 would be a "simple objective" because all other aspects (sub-processes 18-20) can be automated. For example, knowledge of results (sub-process 19) is actually provided by a light signal directly to each learner as part of the automatic classroom communication system described earlier. Sub-process 30, which says that instructions or "cues" should be provided by the teacher while the learners are attempting to discover a higher level task, is simply a programing problem. The same instructions or cues could be provided in written form or by tape recorder.

Objectives 4, 5, and 6 are also complex objectives, although the latter two could perhaps be treated as simple objectives. Providing intermittent teacher approval for successfully applying a general law might be accomplished with a signal or tape recording just as effectively.

Figures 5 and 6 illustrate two different plans for still another subordinate objective which can be learned through discovery or by other methods. Sub-fact 9 is the conventional order of operations (multiply first, then add). Typically, in the UICSM materials, students are not required to "discover" a convention; however, in the design of the present instructional materials, it was decided that the learners should have the experience of "discovering" that there is need for such a convention before being told the convention. Plan A for sub-fact 9 is outlined in Figure 5. The first box in the flow chart indicates that the program should explain to the student the reason for the order of operations rule then to give examples and cite the rule. Next, the diamond

Figure 5. Plan A for sub-fact 9, "Convention: multiply first, then add."

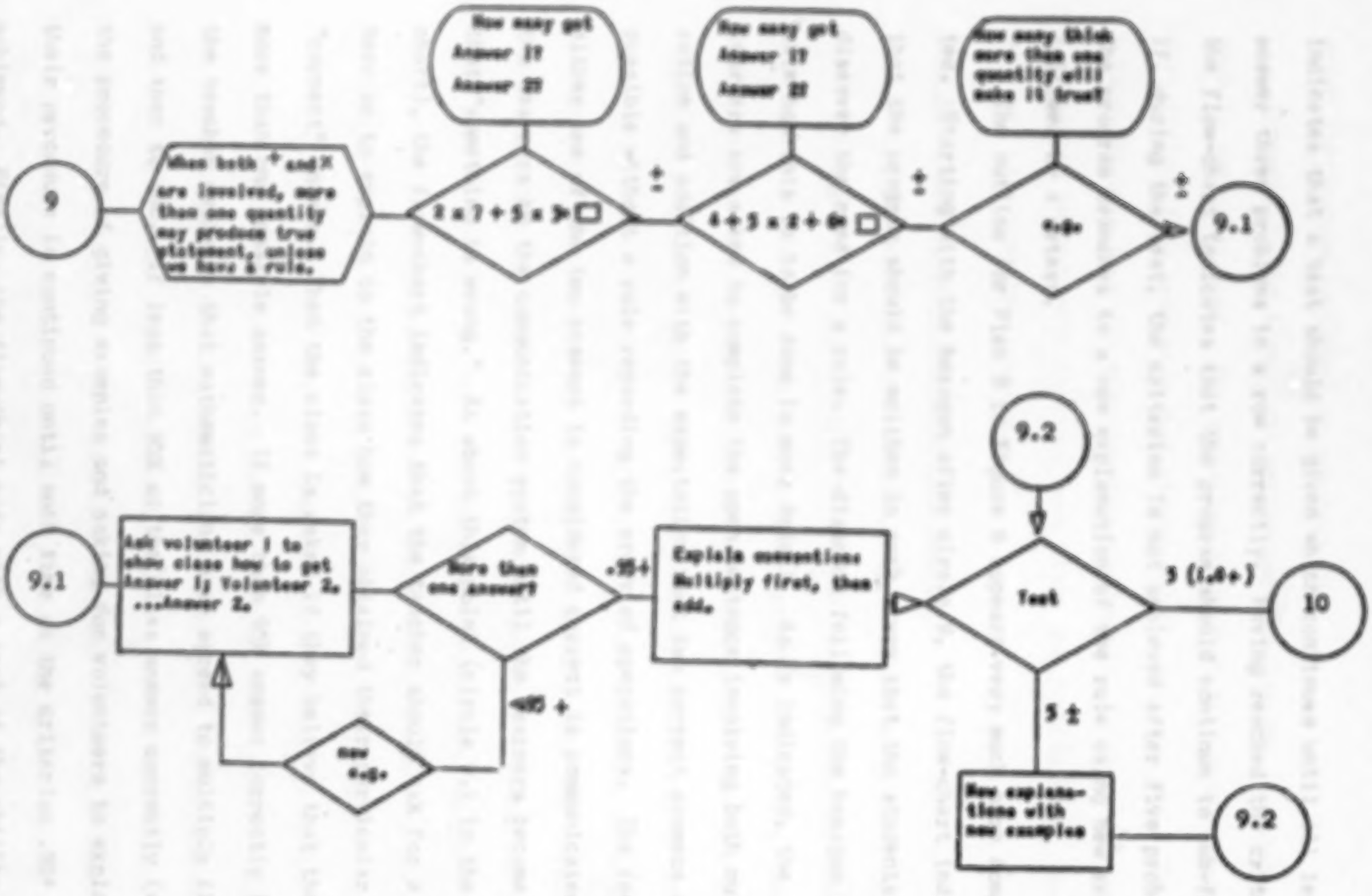

9
When both + and × are involved, more than one quantity may produce true statement, unless we have a rule.
How easy get Answer 1? Answer 2?
How easy get Answer 1? Answer 2?
How easy think more than one quantity will make it true?
9.1
9.1
Ask volunteer 1 to show class how to get answer 1; Volunteer 2, ...answer 2.
More than one answer?
Explain convention: Multiply first, then add.
9.2
Test
3 (1.0+)
10
5 ±
New explanations with new examples
9.2
new e.g.

Figure 6. Plan B for sub-fact 9, "Convention: multiply first, then add."

indicates that a test should be given which continues until all learners answer three problems in a row correctly. Having reached the criterion, the flow-chart indicates that the program should continue to sub-fact 10. If, during the test, the criterion is not achieved after five problems, the program branches to a new explanation of the rule using new examples followed by a retest.

The outline for Plan B in Figure 6 appears very much more complicated. Starting with the hexagon after circle 9, the flow-chart indicates that the program should be written in such a way that the students should discover the need for a rule. The diamonds following the hexagon indicate how this is to be done in more detail. As is indicated, the learners are asked to complete the open sentence involving both multiplication and addition with the expectation that two correct answers are possible without a rule regarding the order of operations. The fact that either one of the two answers is considered correct is communicated to the learners by the communication system until the learners become aware that "something is wrong." At about this point (circle 9.1 in the flow-chart), the flow-chart indicates that the teacher should ask for a volunteer or to explain to the class how they obtained their particular "correct" answer. Then the class is asked if they believe that there is more than one possible answer. If more than 95% answer correctly (.95+) the teacher explains that mathematicians have agreed to multiply first and then to add. If less than 95% of the class answer correctly (<.95+) the procedure of giving examples and asking for volunteers to explain their procedure is continued until such time as the criterion .95+ is achieved. Finally, the flow-chart ends with a test of the ability of the students to use the rule. The test has a criterion of "3(1.0+)" after

which the program continues to sub-fact 10.

Presumably, the flow-chart writer could modify the learning experience in yet other ways. The appealing feature of this methodology is that it indicates precisely what changes are to made and why. This is a happy feature from the experimental standpoint. It also indicates how changes can be made with relative ease after the fashion of an "executive routine" in a computer program.

Step 4. Combination of Separate Flow Charts.

Having prepared flow charts according to specified process requirements for each of the subordinate facts, the flow-chart writer then shifted his attention to the instructional program as a whole. Some process statements can be applied only from the perspective of a single continuous program of instruction. For example, sub-process 20 specifies that instructions from the teacher (program) gradually be withdrawn. More detailed instructions to the programer specify that the instructional procedure for each of the "discovery" frames (hexagons) in the flow chart be examined to determine that more help (cues) is given to the learner in the beginning stages of the program than at the end. For example, in the discovery program for sub-fact 10 (Figure 4) the learner is helped with frames and symbols in his efforts to answer the question, "Are there other names for 10?" If the same question were asked toward the end of the program, these cues would not be provided. Instead, the learner would be expected to employ frames spontaneously. Since the discovery frames are clearly identified in the flow chart and the programing instructions are specific, this task is much easier for the programer than it otherwise might be.

Another place where the "overall look" is required is in connection with the programer's attempt to insure that subordinate knowledge is immediately accessible to memory. To insure that information learned at the beginning of the instructional experience is remembered, the combined flow chart for the entire instructional program is scanned to insure that appropriate practice schedules or "review experiences" are built into the program. It is also necessary to anticipate future objectives in earlier ones. Such scanning is readily accomplished with the flow charts when it would be almost impossible working from a detailed instructional program.

Step 5. Development of Specific Instructions and Materials.

Using the flow charts, a materials production specialist and programing specialist operated independently in the final preparation of the instructional program. The programer required only about one hour of instruction on the technique and the notation employed. While preliminary drafts of instructional materials were being tested on one or two subjects individually by the programer, other materials, already approved, were being converted to tapes and transparencies for overhead projection by a second research assistant. The second assistant also tried the materials on small groups of children using the special classroom communication and display equipment for which the materials were prepared. Thus, a staff of three specialists worked fairly independently in the production of a single instructional program. Each person, a specialist in his own right, worked at a different level in the development of the materials.

The Effectiveness of the TRAC Procedure.

The unit of classroom instruction upon which the programed materials were based had been tried out on several groups of fifth graders to

insure that the instructional procedures were appropriate for that age level before the programing effort was even started. Subsequently, the programed modification called the "programed discovery" procedure was tried out with individuals and then with several small groups of fourth and fifth graders in the process of its development. A total of 15 children completed the entire instructional program before it was even used in the experiment. Because prior work with the program was so comprehensive, the third instructional procedure called the "programed guidance" procedure actually was created out of the programed discovery unit only a few months prior to the time when the experiment was begun.

Solutions to problems of "individual differences." Even though the instruction was paced to the slowest learner, individual differences in learning rate posed no great difficulty. At one point in the program, special handling of the learners was required when faster learners discovered the basic pattern several hours before slower learners. This problem was handled simply by removing the rapid learners from the group and providing them with work in other subject matter areas until the slower learners caught up. Thereafter the learners continued as a group to the completion of the program without difficulty.

Because the groups employed in the experiment were considerably larger than those employed in the development of the program of instruction (groups of 15-20 as contrasted with groups of 5) some problems arose in the experiment which were not anticipated during the developmental phase. Individuals in the larger groups, for instance, were much less likely to interact among themselves than those in the smaller groups, and because they were more heterogeneous with respect to ability and interest, problems of a disciplinary sort arose more frequently in the

larger groups. Most problems were handled effectively by the classroom instructors who were skilled elementary school teachers. One group phenomenon was observed, which appeared to be unique to the instructional technique, and which was partially resolved by a slight modification in the instructional system. The solution is worthy of special note because it has implications for the development of future man-machine systems of this sort.

Because the learners received individualized feedback through the electronic communications system (red and green light signals), there tended to be a much closer interaction between the individual learner and the materials with which he was working, even though the instruction was group-paced. Consequently, the group appeared to "fractionate" during those phases of the instructional process which were largely automated. By this is meant that individuals who were more rapid learners tended to be less patient with the slow pace of instruction which of necessity was paced to the slowest learner. Similarly, the slower learners, recognizing from the behavior of others in the classroom that they were slowing down the group, appeared frustrated and threatened. On occasion, the slow learners would simply give up and enter into distracting social behavior with their seatmates.

The solution to this problem was to redesign the instructional system so that individual learners in the classroom could see the meter which registered the proportion of learners in the class who responded correctly to each question. Then the teacher instructed the learners on his use of the meter and let them know at the beginning of each exercise that the exercise would continue until everyone succeeded in responding correctly to three problems in a row, or whatever the learning

criteria happened to be.

After the use of the meter was made known, the group appeared to become more cohesive. Faster learners reacted with greater tolerance toward the slower members in the group, and even offered comments of encouragement to them from time to time. Possibly because of the change in the reactions of the faster learners, the slower learners appeared more relaxed and challenged by the instructional process. It became more evident to individuals in the class that they were not always the ones who were last to respond when the needle of the meter continued to respond after they had registered their response. In effect, the meter acted as a kind of "governor" for the group.

Spontaneous reactions of learners. Another observation which indicates the effectiveness of the TRAC procedure has to do with the excitement with which the children sometimes reacted to the instructional materials. Excitement did occur more with the smaller groups employed in the preliminary development of the materials, and it tended to occur less frequently as instruction progressed beyond the first five or ten hours. Nevertheless, the children were observed to question each other, argue and to challenge "Mr. Console," which was the name given the tape-recording unit. In this respect, they displayed precisely the type of behavior children sometimes exhibit under the direction of skilled teachers in the UICSM program. In this case, however, the children were reacting to a highly structured set of materials being manipulated by a teacher who, in the beginning, was skilled only in conventional techniques of classroom instruction.

Orienting the instructors. It is also worthy of special note that both instructors used in the experiment were relatively unfamiliar with

the Distributive Law and with the UICSM notation initially. Furthermore, only one instructor had a working knowledge of electronic equipment. The teacher, inexperienced with the equipment, joined the project staff only a few months prior to the beginning of the experiment. He learned to operate the TRAC facility and successfully taught with the programed discovery materials after only a few days of orientation. Since he had no prior knowledge of the Distributive Law or of the UICSM notation he was, in effect, "teaching by rote." Still, the learners in his initial group were not significantly different in their measured performance than those who learned under the direction of the instructor who had been with the project from the beginning and who by then was thoroughly familiar with the instructional content and procedure. On the basis of this observation, it is reasonable to believe that almost any experienced teacher could teach the Distributive Law of arithmetic by the discovery method using the programed materials developed for the present experiment.

Educational researchers will recognize the advantages inherent in a procedure such as the one described above which adds precision to the preparation of instructional materials. From the flow-chart diagrams, it is quite possible to identify those portions of the instructional program which were designed for specific subordinate objectives or to represent particular methods of instruction. Furthermore, because the behavior of the teacher is standardized, comparisons can be made between variations in research treatments with assurance that error variances attributable to teacher effectiveness will be minimized. Because the instructional experiences are standardized, design features of classroom experiments can be replicated systematically.

III. Implications: Designs for Instruction

By far the major effort in this present project was directed at the development of a procedure for programing classroom instruction. Consequently, it should not be surprising that the project implications have more to do with designing instructional units than they do with the research problem, learning by discovery. In the sections which follow an attempt is made to conceptualize the unique roll of the teacher in the technologically based classroom and to deal with a relatively new kind of research problem, the inhibitory effects of compounded instructional designs. Research on the inhibitory effects of compounded designs will have to do with problems of sequencing and ordering instructional experiences, and with "crowding together" two or more instructional objectives in a single instructional unit. Research dealing with problems of this sort is made possible by procedures such as those used in the present project wherein extremely complex classroom-type instructional processes extending over prolonged periods of time can be designed, developed, and conducted with precision.

Finally, as an implication of the research effort, per se, a section is devoted to the problem of arousing and maintaining student interest in learning during instruction. The behavioral manifestations of "interest" will be discussed in the context of learning strategies for attaining complex instructional objectives.

The Unique Role of the Teacher

Instructional technology is advancing rapidly to the point where procedures such as those employed in the development of the instructional units for the present experimental effort will be commonplace.

It is almost inevitable that future instructional techniques will place heavy reliance on autoinstructional systems such as those employed in the TRAC facility described in the second chapter of this report. Upon considering such teacher developments, it is easy to draw parallels with the advancing technology centering around computer systems which has more to do with military operations and industrial management than it does with education at this point. In the realm of computer applications, however, there is the possibility that human functions may eventually be almost completely taken over by electronic and electromechanical devices. It is common knowledge that machines are replacing men in many vocational areas. But it is not common knowledge that machines are replacing human beings in management and control activities which involve decision-making, problem-solving, and creative design. Many scientists and engineers are devoting their creative talents fully towards the objective of complete automation in our present society. It is not difficult to shift into the educational arena and to make predictions concerning the development of completely automated instructional systems--systems which can direct the learning processes leading to complex instructional objectives, successfully and without human intervention.

Taken at face value, and out of the context of social progress in general, there is no tangible reason to be concerned about developments in the direction of complete automation. It requires a great deal of imagination to conceive of a world dominated by machines wherein human beings are subordinate. One simply must have faith that the human being is intelligent enough to adjust to a world which is becoming increasingly more automated. Already, many creative minds are considering

strategies for the vocational re-education of adults who are already feeling the impact of automation; and it is only a matter of time before serious thought is given to redesigning the public school curriculum in anticipation of social problems arising out of increased opportunities for adults to live productive lives without being required to "earn money."

However, we are at a choice point in developing instructional systems. Even though it is not evident from our present level of technological advancement that instructional systems will become completely automated in the immediate future, we should face up to that possibility.

Engineers sometimes perceive man's capabilities as "gap fillers" in what ideally would be completely automated systems. If the research and development of instructional systems is conducted by individuals with the latter viewpoint, the trend will be almost inevitably towards completely automated instructional systems. For convenience in this present discussion, future developments which emphasize machine aspects will be described as "man-machine" instructional systems.

If, by contrast, the emphasis is placed on the unique role which the human being can continue to perform in instruction, future research and development may lead to what will be described hereafter as "augmented human" instructional systems. The concept of augmented human instruction can be traced to Dr. Douglas C. Engelbart, Research Engineer at Stanford Research Institute (SRI), and his very interesting program of developmental research in computer technology. For over ten years Engelbart has been conceptualizing an approach to the design of computer systems which identifies and augments distinctly human capabilities. An interdisciplinary team of research scientists at SRI is presently

engaged in the development of a special input-output system which will permit human beings to interact directly with an electronic data processing unit. One research effort is already anticipating the problems of training human beings to effectively interact with a data processing system which has been specifically designed to enhance their intellectual capability.

Obviously, both man-machine and augmented human instructional systems may be researched simultaneously, or only one approach may be selected. Herein lies the choice: shall we do both, or simply continue to emphasize the man-machine instructional system?

In the present project two instructional procedures were developed which are representative of the two approaches identified above as man-machine and augmented human instruction. The directed discovery procedure is representative of a man-machine system and the free discovery procedure is representative of augmented human instruction. In the next two sections the implications of these two procedures as employed in the present project are discussed.

Man-machine instructional systems. The human being is far superior to any man-made device in searching for and identifying patterns, and in making decisions. Consequently, most military and industrial systems involve both men and machines. In man-machine systems, man is frequently employed only as a practical expedient, not because the task he performs cannot be automated. When this is the case, the man-machine system sometimes suffers because man is an unreliable creature when "misused." In other cases, however, the engineer employs the human animal because he can perform tasks which could not be performed otherwise and because man has the added advantage of being lightweight, flexible, mobile, and

completely independent.

In the development of the programed discovery procedure, the teacher was quite frankly "built-in" to the system primarily because only a human being can perform the tasks which were assigned to the teacher. As was explained in the second chapter, the teacher's role in the programed discovery procedure was to assist the learner in attaining complex objectives. The unique role of the teacher in the programed discovery procedure was to perform the following tasks:

1. To identify approximations of the class of complex behavior described in the instructional objectives from among a great variety of other behaviors manifested by the learners during instruction. No "optical scanning" device known to this present writer has yet been devised which can perform this particular operation.

2. When the desired behavior was not evident, the teacher was expected to interact with the learners in an effort to elicit approximations of the desired behavior.

3. Finally, the teacher served as a feedback channel for the learners by informing them when they were eliciting the correct behavior or approximations thereof, and also attempted to act as a reinforcing stimulus by registering teacher approval of the learner's efforts at the appropriate times.

Although the instructor controlled the operation of equipment in part--at least he started and stopped it--what he did, when, and how were prescribed rather completely. He followed a script which told him as often as not exactly what to say and when to bring his unique capabilities into the system. When his unique capabilities were not required, his responsibilities were limited to maintaining order in the classroom

and pushing buttons to control the instructional system.

There can be no doubt that the instructional procedure was effective. It was developed systematically to the point where it did produce the desired behavioral outcomes. But, in the interest of precision in research, the emphasis was placed on prescription and automation in the instructional process. It was considered important to design the instructional procedure so that it could be employed repeatedly with predictable results, or so that similar procedures could be used in the development of other instructional units dealing with other subject matter. Had the objectives been simply to produce the most effective instructional experience, more reliance would have been placed on the teacher.

Although the programed discovery unit was well developed, there were days when the instructional procedure simply did not appear to be working with a particular group, and such "bad days" came at different points in the instructional sequence for different groups. The instructors in the TRAC facility on such occasions reported that it was difficult for them to refrain from over-riding the instructions and attempting to employ their own skill in teaching to best advantage. They also reported that, although the instructional procedure was often surprising in its effectiveness, it did seem to have a palling effect on the learners. The excitement and enthusiasm which the children displayed during learning was sometimes explosive during the beginning days of the instructional sequence, but such enthusiasm for learning was not often observed during the final weeks of the 21 hours of classroom instruction.

In short, something definitely was lacking in the man-machine instructional system represented by the programed discovery procedure. The missing ingredient may have been the "human element."

Augmented human instruction. The free discovery method was essentially the same as programed discovery with respect to the topics covered, stimulus materials employed, and the sequence and branching arrangements of the programed version. The one essential difference was that the instructor was given complete freedom with respect to the way he employed the materials, and with respect to his interactions with the learners. Although the teachers logged their progress and other essential information after each day's activity, no detailed records were kept regarding their interactions with the learners. We know only that they followed the same general outline, used the same materials, and modeled their instruction after the UICSM instructional technique. The relative effectiveness of the free discovery procedure has been reported in Chapter I. To summarize briefly, in the free discovery group criterion was reached in less time than required by the programed discovery procedure, a larger proportion of the learners reported that instructional experience was "difficult," and a larger proportion of the learners employed searching behavior on a test of new learning following instruction. At this point it is difficult to account for these results in any other way than it was in the first chapter wherein it was presumed that the instructor was more effective in pacing the learning process and in interacting with the learners so as to arouse and maintain interest throughout instruction. Also, the classroom instructors reported that in the free discovery procedure, less reliance was placed on the classroom communication system so the individual learners were inclined to interact more with one another. Interaction among learners in the programed discovery procedure was limited primarily because the learners received direct feedback regarding the effectiveness of their responses to the instructional materials by

light signals from their response consoles.

Again, it may have been the "human element" that made the difference. The next problem is to identify precisely what the teacher does in the free discovery procedure to make the difference. It may be presumed at this time that the difference stems not so much from the fact that the teacher is less restricted in his behavior, but rather that he does something in the free situation which was programed out of the programed discovery procedure.

The net result, in any event, is that there is a difference in the effectiveness of instructional systems when used to augment human instruction. When the human being is simply incorporated into the system, the system may not work so effectively.

Inhibitory Effects in Compounded Designs

Typically, laboratory studies of human learning employ instructional units which are relatively simple in that they can be completed in a short period of time. Seldom are experimental subjects required to participate in a laboratory exercise for more than several hours, and the data from these studies provide us with much of what we accept as a matter of principle in designing instructional programs lasting over a period of weeks or months. The instructional unit employed in the present project was different in that it involved very complex instructional objectives which required an average of 16 hours of classroom instruction to complete. Consequently, the task of identifying the components of the learning task and of arranging these components into a sequence all presented problems which have not been scientifically researched. The best we have to go on at this point are the findings of

the laboratory researchers who have been working on problems of verbal learning which involve paired-associate and related tasks and materials. But evidence from such studies can hardly be expected to apply to all problems of arranging instructional experiences which are spaced in hourly units on a daily basis over a period of weeks.

One of the more obvious requirements in designing prolonged instructional sequences is that provision be made for a periodic review of behaviors learned early in instruction. As one attempts to take into account review procedures, he is immediately confronted with the realization that review is often unnecessary because it is essentially built into the instructional materials at later stages in the learning process. If a learned behavior is truly a step in the learning process leading towards a particular objective, the previously learned behavior will almost certainly be employed in the context of learning advanced behaviors.

There are occasions, however, when a large amount of seemingly unrelated behaviors must be learned independently before they can be integrated or otherwise employed in higher level tasks. This was true in the present project during the first few days of instruction when it was necessary to teach the fifth graders the terminology and rules for using the UICSM notation. Besides learning about "frames," "open sentences," "mathematical sentences," and "mathematical statements," the learners had to learn several conventions for using the notation, such as the order of operations and the use of parentheses. By the time some learners were learning about the order of operations, they had forgotten the definition of the mathematical sentence which was the first definition they learned. Obviously, it would have made little difference whether they learned the order of operations before or after the definition of a mathematical sentence.

Another problem was encountered when, in the last stages of instruction, it was necessary to teach the learners some specific rules and names for behaviors they had been acquiring along the learning route. The instructional unit had to be terminated at some point, but because of the practice requirements before the final learning objectives, it was difficult to identify a convenient stopping place. At the same time, it was apparent that the earlier learning tasks, although essential as tools for the learner to employ in his thinking with numbers, no longer were directly related to the ability of the learner to recognize the distributive pattern.

So, in the relatively short unit of instruction involved in the present project, it became apparent that there are very real unresolved problems of human learning which can only be attacked by studying learning strategies involving a number of learning objectives that build one upon the other in the direction of some higher level task. A more concise statement of the problems identified above and others will follow. Consider first some problems involving the sequencing of subordinate objectives, and then some problems having to do with "crowding together" more than one instructional objective into one experience.

Sequence effects. It should be made clear at this point that the list which follows is not intended to be exhaustive. Rather, it reflects the experience gained from the present developmental research effort. No attempt has been made to cross-validate the observations with other instructional objectives, other materials, or other groups.

1. The procedure for analyzing objectives described in Chapter II is an effective way to start an instructional design, but it is dangerous to presume that the hierarchy of subordinate objectives and processes

arrived at initially is necessarily complete or correct in terms of sequence. It is quite easy to overlook an important step or to include one which should be omitted. In the programed discovery procedure, for instance, the learners were taught to identify examples of the distributive pattern from other examples which were not examples of the Distributive Law. It is quite likely that this objective could have been attained much more directly than it was, but it was considered important to teach the learners some of the UICSM notation. Consequently, the test of recall was as much a test of the learner's knowledge and facility in using the UICSM notation as it was their ability to identify and to employ the Distributive Law of arithmetic. Since the learning experience was terminal in nature in that there was no follow-up to it, and it did not lead to an established course of instruction, one wonders if there may have been a more direct way of teaching the Distributive Law to the fifth graders without involving them in a new notation system. Perhaps it could be shown that requiring the learners to learn the notation early in instruction had an inhibitory effect on subsequent learning which was more specific to the Distributive Law, per se.

2. As a design requirement for the programed discovery procedure, the learner was to employ subordinate knowledge in discovering (ascertaining) higher-level tasks repeatedly throughout instruction. However, it was not always possible to prescribe the learning experience in such a way that the learner could discover an instructional objective, simply because many of the objectives were definitions or conventions. Definitions and conventions have to be told; they cannot be "abduced" (see discussion under "Related Research," Chapter I; also, Hanson, 1958, p.85). The effect on the overall instructional pattern was that discovery-type

experiences were interspersed more or less frequently with others which involved simply rote learning. Over all, the effect was that the learners' discovery experiences were sporadic. At some points during instruction several days intervened the learner's opportunity to engage in the kind of exploration and manipulation which was being designed into instruction. Again one wonders what inhibitory effect the interjection of lecture-drill type procedures into the main stream of instruction may have had on the experimental findings.

3. It was a practical requirement of the inst uctional setting that the learners be scheduled in one-hour instructional periods each day as is conventional in the administration of schools and colleges today. As a result, there were times when the learners had to be interrupted in their efforts to ascertain a particular instructional objective at a time when it may have been advisable to let them continue. Also, there were days when the learners simply were not responding effectively to the instructional materials, and it may have been better to postpone instruction rather than to complete the hour in keeping with the instructional schedule. It has long been established that problem solving may be more effectively accomplished when the learner is allowed to continue without interruption for so long as he may wish, whereas learning which is aimed at acquiring increased skill through practice may be more effectively spaced over time. It may be predicted that considerations of massed versus spaced practice will once again become of serious concern in studies of learning processes such as those involved in the present research effort.

4. As was explained in Chapter II, the instructional design was based on a hierarchy of subordinate facts and processes to be learned

sequentially. It was presumed that each subordinate objective should be mastered before moving on to the next objective. However, as it turned out, a large number of the objectives involved could have been learned in almost any order. .It may have done more to inhibit learning than to facilitate it to require that the learner master each of the subordinate facts step-wise when the subordinate objectives could have been learned in almost any order. It may have been better to present examples showing different aspects of the notation system simultaneously so that the learner could make comparisons among the various elements in the system which eventually had to be descr'minated.

Instructional "crowding." It is realistic to deal with more than one instructional objective at a time. However, it should be a matter for serious concern whether the instructional objectives are attained simultaneously or sequentially. When too many objectives are included in a single instructional unit, the complexity of the learning experience may do more to inhibit learning than enhance it.

The results of the present experiment may reflect instructional crowding in the programed discovery procedure. It may be recalled that the programed guidance procedure was essentially the same as the programed discovery procedure except that certain experiences were omitted. The research evidence indicated that the programed guidance group was superior to the programed discovery group, at least with respect to the frequency with which the learners employed searching behavior in the test of new learning. Perhaps if the instructional design for the programed discovery group had attempted a limited number of the objectives involved during the first fifteen hours of instruction and then concentrated on the remainder afterwards, the effectiveness of the program would have

been increased. In this way the number of objectives to be learned at any one time would have been reduced because they would have been spread out over time. The "spreading out" of instructional objectives would have increased the length of the learning period, but it also may have markedly increased the effectiveness of the program.

Arousing and Maintaining Student Interest

Bruner (1961) maintains that discovery learning fosters interest in the activity of learning itself rather than in the rewards which may follow from the learning. Kersh (1962) reports evidence that this interest in the learning activity persists beyond the instructional period and maintains practice behavior for weeks thereafter. The motivating effect of learning by discovery has been attributed to the learner's natural curiosity and attraction to "what-would-happen-if" question (Heberman, 1958).

If more were known about the conditions which arouse and maintain the motivating effect associated with learning by discovery, then programers of self-instructional materials could build into their programs those experiences which produce the motivational effects and counteract the palling effect which many programs have on learners, especially faster learners. Classroom teachers also could use documented techniques to foster continued interest in the learning task between class sessions. Eventually, techniques of instruction might be developed which would motivate learners to continue practicing for sufficiently long periods of time after instruction to link together widely separated courses of instruction dealing with the same subject matter. The motivating effect of discovery learning can be explained in a number of possible ways. It could be a manifestation of a drive to explore new environments and to

manipulate objects. Such behavior has been observed and documented in experiments with animals. It could also be explained in terms of psychoanalytic ego psychology as an "instinct to master" which is manifested initially in the behavior of infants (sucking, grasping, manipulating, etc.). Yet another explanation may be that most human beings need excitement and novelty to escape the boredom of routine. Viewing exciting stories and events on television, and driving cars at high speeds are only two common examples of activity used to satisfy this need.

It would not be particularly appropriate in this report to review and to document all the possible theoretical explanations for the motivational effect which is frequently associated with discovery learning. Actually, such a review has already been reported recently by White (1959) who incorporated existing notions into the concept of "competence motivation." White's concept of the competence motive, which he calls "effectance," fits particularly well in this present line of research. According to White, when human beings engage in an activity that is exploratory in nature, involves manipulation, and produces novel results, they may be motivated to continue the activity by an urge to become competent or proficient. As was pointed out in the discussion of the experimental results reported in Chapter I, an important aspect of White's notion is that the rewarding feature of competence motivation stems from the arousal and maintaining of activity, not from the completion of the act. The contrasting experimental procedures reported under "Related Research" in Chapter I illustrate particularly well how two procedures, both classed as discovery procedures, can actually differ markedly with respect to the conditions which may arouse and maintain student interest.

The stress which this present writer has placed on the motivational effects of learning by discovery does not stem from a primary interest in motivation. Rather, it has come about through a continuing search for evidence which will (1) verify or refute the pedigogical notion that discovery learning is superior to other learning procedures, and (2) explain the superiority of discovery learning under conditions where it has been demonstrated to be superior. The arousal of student "interest" in an activity is considered important primarily because of the behavioral outcomes of such interest, not simply because instruction should be appealing to the learners.

It was pointed out in Chapter I that the research evidence is equivocal with respect to learning by discovery. The reported research evidence which does tend to favor the discovery procedure was obtained under conditions which are nearly identical with respect to opportunities for manipulation, exploration, and novelty (Kersh, 1958, 1961; Gagné & Brown, 1961). The question remains, however, whether the superior performance of the discovery groups (in the experiments cited) can be attributed to learning outcomes from the instructional experience or to long established behavioral tendencies which were restimulated during the instructional experience. The results from this present experiment would support the latter view. In the present experiment, <u>all</u> instructional procedures were effective in fostering interest. The free discovery group's tendency to more frequently employ "searching behavior" actually may be attributed to "competence motivation" which results from increased opportunities for learners to manipulate symbols and to explore new ideas.

To be more specific, some of the desirable behaviors which are

associated with "learning by discovery" (see discussion under "Problem," Chapter I) may become evident when nondirective teaching methods are employed, but only under very special circumstances which have yet to be precisely determined. It is hypothesized that, when the desired behaviors do become evident, they are manifestations of a very well established behavioral tendency. Possibly White's concept of "effectance" (competence motivation) is the underlying behavioral tendency. White describes effectance as follows:

> "Effectance is to be conceived as a neurogenic motive, in contrast to a viscerogenic one. It can be informally described as what the sensory-neuro-muscular system wants to do when it is not occupied with homeostatic business. Its adaptive significance lies in its promotion of spare-time behavior that leads to an extensive growth of competence, well beyond what could be learned in connection with drive-reduction." (White, 1960, p. 103.)

The conditions which arouse the competence motive deserve a great deal of further study. By systematically manipulating instructional variables in programs such as those employed in the present experiment, it may be possible to identify more precisely the circumstances under which such "motivated" behavior occurs. Until we can develop materials and procedures of instruction with confidence that they will arouse the desirable student behavior in question, we will not be in a position to use it as an instructional tool for increasing the desirable learning effects commonly associated with "discovery."

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